RESULTS OF POST-IRRADIATION EXAMINATION OF INERT MATRIX FUEL COMPOSITIONS IRRADIATED IN BOR-60 REACTOR UP TO 19 at.% UNDER THE RUSSIAN-FRENCH EXPERIMENT BORA-BORA

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In the frame of the MINATOM (Russia) - CEA (France) collaboration…

Selection and development of techniques to produce inert matrix fuel compositions and research of their radiation resistance are actual for use of plutonium and transmutation of minor-actinides.

In the frame of the MINATOM (Russia) - CEA (France) Agreement on fast sodium reactors experiment BORA-BORA was performed to investigate different fuel compositions with high plutonium content under the BOR-60 conditions. Among them:

Fuel composition 1: 40% PuN+60% ZrN – 2 fuel pins.

Fuel composition 2: 40% PuO_2 + 60% MgO – 2 fuel pins.

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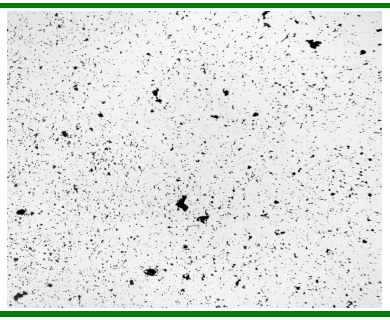
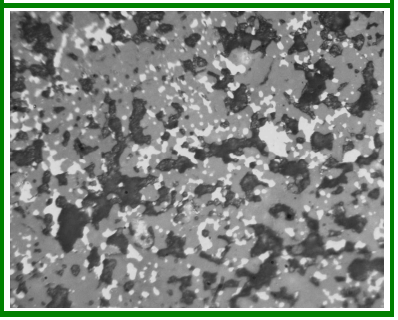
Manufacturing characteristics

Fuel composition	40%PuN+60%ZrN	40%PuO_2+60%MgO
Pin number	7R, 9R	13Pl, 23Pl
Pellet density (%Dth)	84	89
Pellet diam. (mm)	5.9	5.9
Diam. Gap (μm)	200	200
Grain size (μm)	25-30	1-10
Fissile stack length (mm)	450	450
Crystalline lattice parameter, nm and Phase composition	0.476 – Pu(Zr)N; 0.470 – Zr(Pu)N Solid solutions (differing ratio Pu/Zr)	0.5395 – PuO_2 0.5198–$Pu_2O_3 \cdot 2PuO_2$ 0.4211 – MgO PuO_2+Pu_2O_3+MgO Mechanical mixture
Microstructure		

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Irradiation data

Fuel pin	Fuel composition	Irradiation time, day	Max. burn up (at. %)	Linear power (kW/m)	Max. clad. temperature, °C	Damage dose in steel, dpa
9R	**40%PuN +60%ZrN**	514	**11.3**	20.7	547	23
7R	**40%PuN +60%ZrN**	900	**19.4**	20.7	543	43
23PI	**40%PuO_2 +60%MgO**	514	**11.1**	10.0	551	23
13PI	**40%PuO_2 +60%MgO**	900	**19.0**	10.0	514	43

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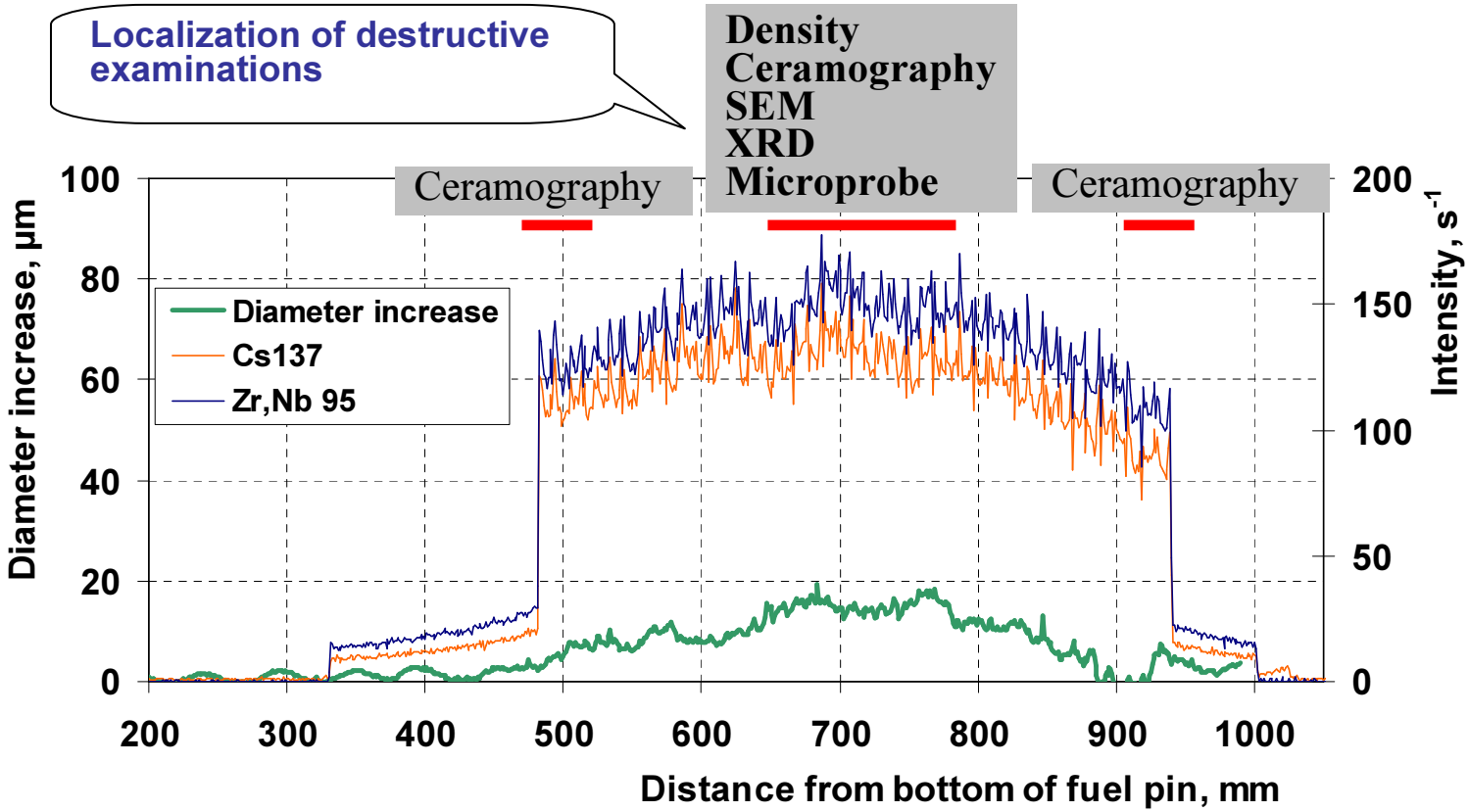
Post-Irradiation Examinations (fuel pin with 40% PuN+60% ZrN, burn up 19.4 h.a. %)

Non Destructive Testing:

- ✓visual control - there were no anomalies;
- ✓ leak-tightness control (^{85}Kr) - leak-tight;
- ✓gamma-scanning - no anomalies in the distribution of fission products;
- ✓ profilometry - increase of the fuel pin diameter less than 20 microns



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Similar results have been obtained for fuel pin with 40% PuO_2+60% MgO, burn up 19 h.a. %

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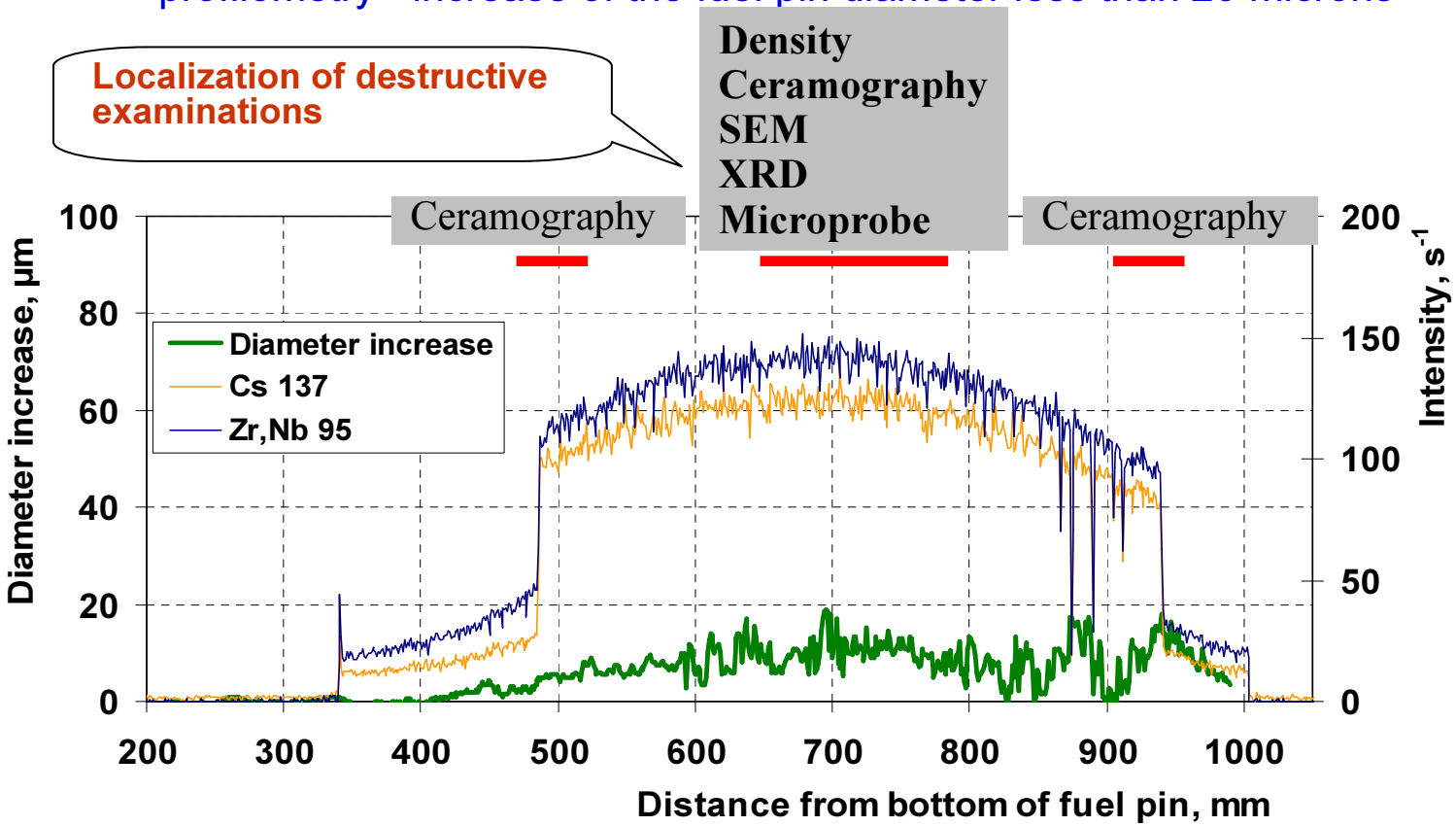

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GAS PHASE IN FUEL PINS (B≈19 h.at. %)

Fuel composition	Gas pressure in fuel pin, MPa (n.c.)	Gas volume, cm^3 (n.c.)	Gas content, vol.%			GFP volume, cm^3 (n. c.)	GFP release, %
			He	Kr	Xe		
40%PuN +60%ZrN	0.09±0.02	11±2.6	83	1	**12**	1.4	**1**
40%PuO_2 +60%MgO	0.13±0.02	17±2.6	62	2.4	**34**	6.1	**9**

✓**Low level of gaseous fission products release**

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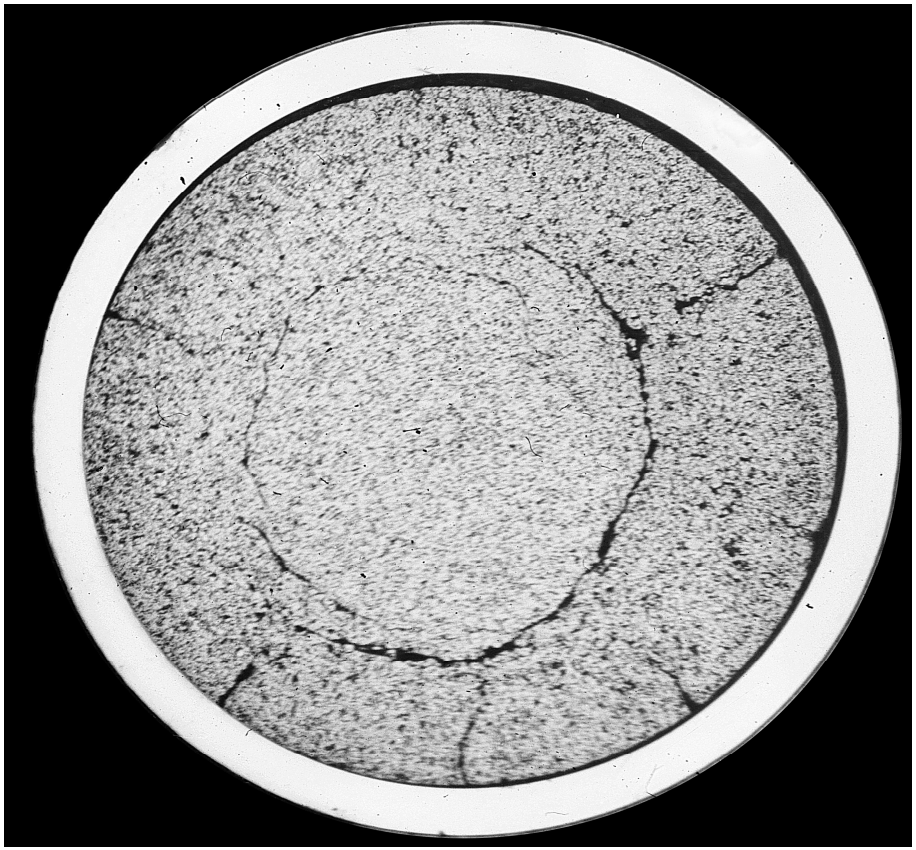
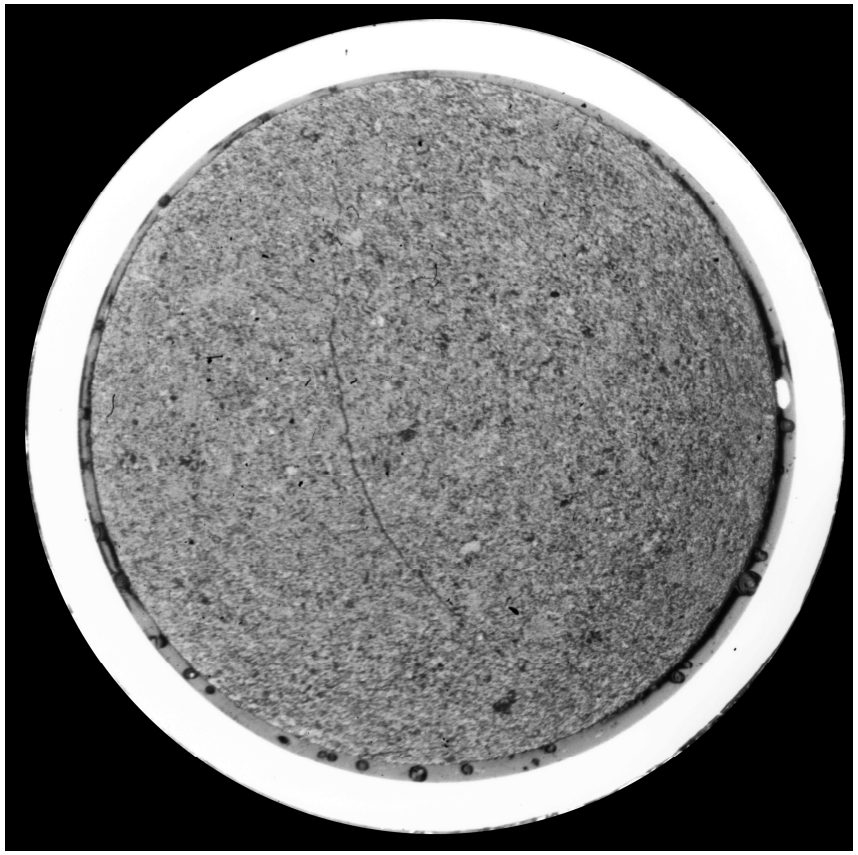
Macrostructure of Irradiated composition

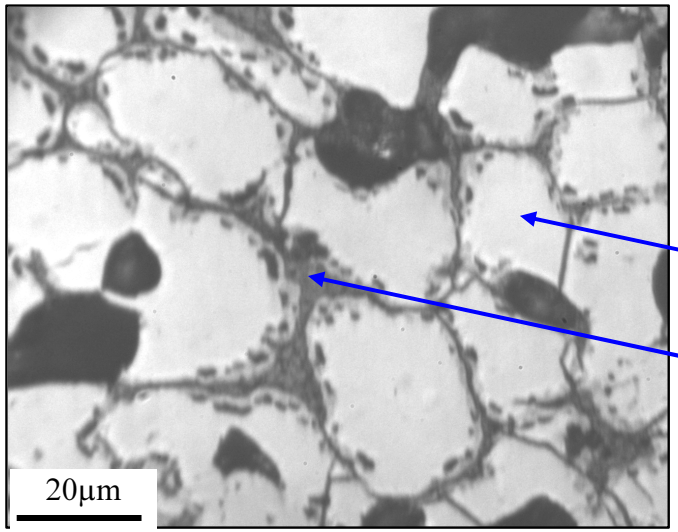




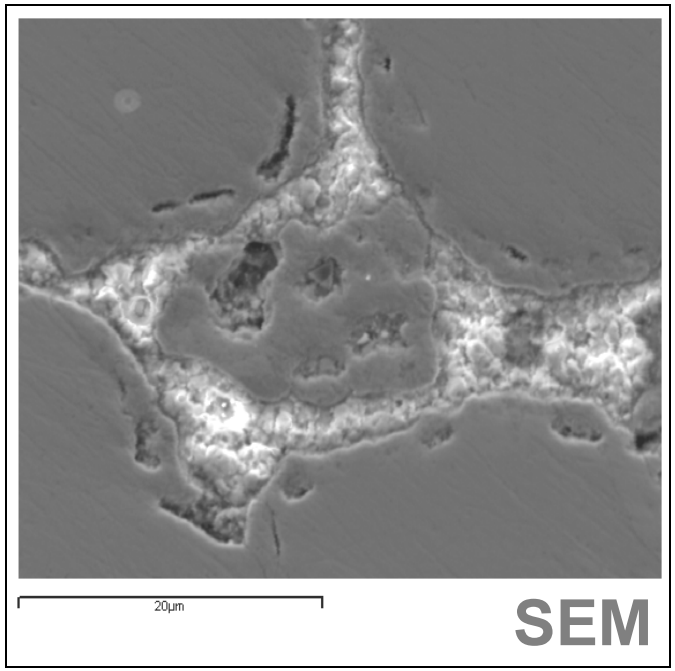
40% PuN+60% ZrN

40% PuO_2 + 60% MgO

DESTRUCTIVE EXAMINATIONS: 40%PuN+60%ZrN



Area of examination	Mass fraction, % (EPMA)							
	Pu	Zr	Nd	Xe	Cs	Mo	O	N
Light phase	25.1 ±2.4	61.1 ±3.1	0.55 ±0.05	0.8 ±0.3	0.64 ±0.13	0.56 ±0.01	1.2 ±0.4	10.9 ±3.8
Grey phase	74.4 ±1.4	6.9 ±1.4	0.9 ±0.2	0	0	1.14 ±0.08	13.5 ±1.7	0

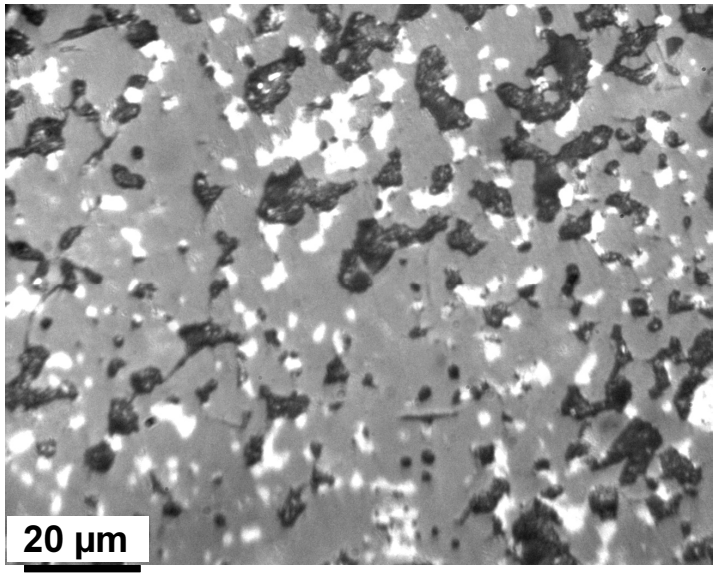


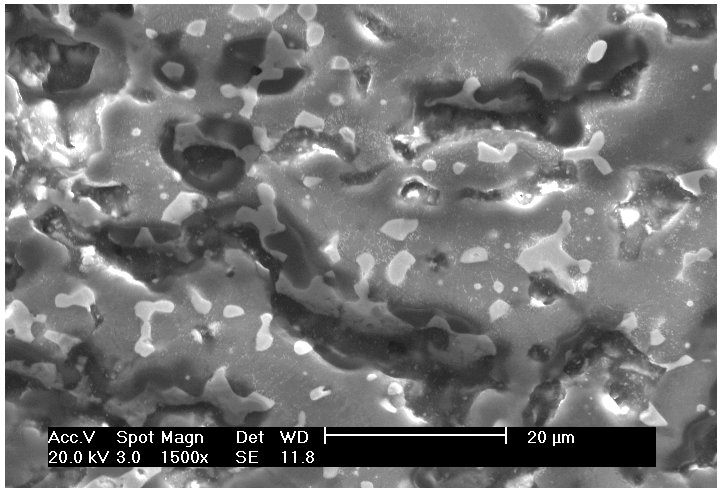
Crystalline lattice parameter, nm

Unirradiated	0.476; 0.470 Pu(Zr)N; Zr(Pu)N
Burn-up 11.3 % at.	0.46432±0,00005 Zr(Pu)N
Burn-up 19.4 % at.	0.46484±0,00004 Zr(Pu)N
ZrN	0.4577
PuN	0.4905

✓ **Two main phases – solid solutions based on zirconium and plutonium nitrides differing in their ratio and FP content**

DESTRUCTIVE EXAMINATIONS: 40%PuO_2+60%MgO





SEM

Material	Crystalline lattice parameter, nm
Unirradiated fuel	0.5395 ±0.0001 (PuO_2) 0.5198 ±0.0001 ($Pu_2O_3 \cdot 2PuO_2$) 0.4211 ±0.0001 (MgO)
Burn-up 11.1 % at.	0.53885±0.00006; 0.42140±0.00001
Burn-up 19 % at.	0.53816±0.00004; 0.42178±0.00003
MgO	0.4211
PuO_2	0.5396

✓The irradiated fuel composition consisted of two phases - PuO_2 and MgO with the crystalline lattice parameters differing from those of pure chemical compounds;

✓ The EPMA showed the fission products in the plutonium-containing phase and in the magnesium-containing one.

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DENSITY AND SWELLING RATE OF FUEL COMPOSITIONS

Fuel	Burnup, % h.at.	Density, g/cm^3	Average swelling rate, %/ 1% at.
40% PuN +60% ZrN	*Unirradiated*	7.45 ±0.05	~ 0.1
	11.1	7.46±0.07	
	19	7.33±0.04	
40% PuO_2 + 60% MgO	*Unirradiated*	4.46±0.02	~ 0.7
	11.3	4.07±0.04	
	19.4	3.92±0.02	

✓**Low Swelling rate of 40% PuN+60% ZrN**

✓**Swelling rate of 40% PuO_2 + 60% MgO is about the same as of MOX fuel**

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CONCLUSION

All the obtained results allow made a conclusion about the expediency of further investigation of

PuO_2+MgO and PuN+ZrN

compositions up to higher burnup and at higher content of a fissile component.